WHITE PAPER ON VLTI POLICY

Established by an *Ad-hoc Committee*
of the *VLTI Implementation Committee*
& endorsed by the *VLTI Implementation Committee*.
December 17, 2001.

In order to establish the convergence of efforts in the ESO Member states for the VLT Interferometer, a special Committee, called "*VLTI Implementation Committtee*", has been jointly established by ESO and the national Institutions which currently contribute to VLTI with additional ressources. Its task is to consider the VLTI implementation, ressources, science objectives and to make recommandations either to ESO through the STC, or to national bodies, in order for Europe to keep its recognized leadership and excellence in the whole area of optical interferometry.

This *VLTI Implementation Committe*, meeting on Oct. 11, 2001 :

- congratulated ESO for the remarkable VLTI technical achievements (followed by the highly successfull coupling of UT1 & UT3 on Oct. 29, 2001);
- recognized the need to review the VLTI long term scientific policy, in order to define and optimize the needed ressources;
- established an *Ad Hoc Committee* for this purpose, with the task to submit a White paper in time for the December 2001 ESO Council, and a complete Blue Book review document for the spring 2002.

The Committee is made, for the first phase, of A. Quirrenbach (elected chair), F. Malbet and T. Henning; it will then be augmented with C. Haniff, D. Queloz, and A. Richichi.

The following White Paper is presented to ESO Council on behalf of the *VLTI Implementation Committee*, and will be transmitted to national Institutions of ESO Member states.

The VLTI Implementation Committee :
Members :
Reinhard GENZEL, Chair
Arnold van ARDENNE
Fabienne CASOLI
Andreas GLINDEMAN
Thomas HENNING
Anne-Marie LAGRANGE
Mario LATTANZI
Pierre LENA
George MILEY
Francesco PARESCE
Hans-Walter RIX
Massimo TARENGHI
Oskar von der LUHE
Rens WATERS
Gerd WEIGELT

Invited Observers :
Willy BENZ (Switzerland)
Chris HANIFF (United Kingdom)
Jean SURDEJ (Belgium)

Recommendations of the Ad-Hoc Committee for the VLTI

Members: Thomas Henning, Fabien Malbet, Andreas Quirrenbach (chair)

Date: Nov 22-24, 2001

Endorsed by the VLTI Implementation Committee, Dec 16, 2001

1. Introduction and Summary of Recommendations

With the achievement of "first fringes" with the UTs the VLTI has demonstrated its potential to assume the leading position in optical/infrared interferometry in the world. The highest priorities for the next few years should be to maintain the momentum in the technical development, and to start a scientifically productive program of astronomical observations. The first generation VLTI instruments – MIDI and AMBER, together with the MACAO adaptive optics systems – will open a large new discovery space by improving the sensitivity limit in the near- and thermal IR by ~ 6 magnitudes compared to current facilities. This will enable many new lines of investigation impacting various fields of stellar astrophysics, and will for the first time give access to extragalactic objects. The next big steps forward will depend on measuring, understanding and eventually controlling the optical path length in the instrument. This will enable astrometry, observations of faint sources, and nulling, and improve the imaging capabilities of the VLTI.

Therefore we recommend that

- high priority is given to making the first-generation instruments scientifically productive
- the astrometric capabilities of the VLTI with PRIMA are developed on the fastest time scale possible
- faint-source capabilities are implemented immediately after this step
- the number of ATs is increased in order to realize large efficiency gains for imaging and astrometry
- second-generation instruments are developed to take full advantage of the capabilities provided by the VLTI infrastructure, including the simultaneous combination of six telescopes.

2. Competitive Situation

Assessing the competitive situation of the VLTI with respect to interferometric projects done elsewhere, we should compare the VLTI with the following other major facilities: the Keck Interferometer, the Large Binocular Telescope, the CHARA array, and the Space Interferometry Mission.

The Keck Interferometer (KI) is the most direct competitor of the VLTI, with many capabilities that parallel those of the VLTI. The scientific objectives of the KI are strongly driven by NASA's Origins Program centered on the detection and characterization of extrasolar planets. The first goal of the KI is nulling at $10\,\mu$m in order to detect exozodiacal light; first observations in this mode can be expected in 2002. In the same time frame the KI will attempt to achieve the first direct detection of an extrasolar planet through the differential phase method. Astrometric observations with 20 μas precision are planned to commence in 2004, depending on the permission for the installation of (fixed) outrigger telescopes. The two 10 m telescopes are equipped with star separators (dual star modules); therefore the KI can perform single-baseline faint target observations.

The Large Binocular Telescope (LBT) will provide capabilities that are mostly complementary to those offered by the VLTI. In the 2005 time frame, the LBT will perform interferometric imaging with a large field-of-view, but lower angular resolution than the VLTI. In addition, the LBT will perform nulling interferometry at 10 μm.

The CHARA array (operated by Georgia State University on Mt. Wilson) is currently undergoing commissioning and starting science observations. The CHARA array has been built for imaging with six (fixed) 1 m telescopes. It will pursue some of the same scientific goals as the VLTI, but it will be limited to fairly bright sources.

NASA's Space Interferometry Mission (SIM) is currently in phase A; its launch is planned for 2009. SIM will perform astrometry at higher precision than is possible from the ground. Therefore it is mandatory that the astrometric science with the VLTI will be done well ahead of the launch of SIM.

The OHANA project aims at using optical fibers to link the major telescopes on the summit of Mauna Kea in the 2003-2005 time frame. Its main strength will be the long baselines (up to 800 m), but only a limited amount of telescope time will be available, and the instrument will be constrained to a few selected wavelength bands. One of OHANA's major goals is to perform observations of extragalactic objects with extremely high angular resolution (but limited uv coverage).

3. Strategic Advantages of the VLTI

The VLTI possesses a few characteristics that are not matched by any other interferometer currently in existence or in the planning stage. These features include

- four large (8 m) telescopes, to be equipped with adaptive optics systems
- very well engineered telescopes and interferometric infrastructure, providing an environment with a low background of vibrations, temperature fluctuations, and other disturbances
- a potentially large number of ATs (up to eight supported by the VLTI infrastructure), which are movable for optimized coverage of the uv plane
- a large talent base in the European astronomical community
- objectives that are driven mostly by scientific priorities, not by programmatic considerations (unlike projects funded by the US Navy or NASA).

The development strategy of the VLTI should aim at capitalizing on these advantages.

4. Science Drivers

The specifications of AMBER and MIDI allow us to reach the following outstanding scientific goals:

- observations with very high angular resolution down to 1 mas allowing to probe the 1 AU-scale of proto-planetary systems
- accessing new types of targets such as active galaxies, enabling studies of the inner 1 pc of the brightest active galactic nuclei
- to detect the spectrum of faint companions, with the goal of reaching hot Jupiters
- to reveal the mechanism of massive star formation
- to characterize the mass-loss and dust formation processes in evolved stars.

In view of the VLTI's main strengths and the competition in the field, we foresee for the near future that the VLTI can have a major impact in the following scientific areas:

Detection and study of the reflex motion of stars hosting planets. This astrometric technique is complementary to the radial-velocity searches and will guarantee that Europe retains a leading position in the field of extrasolar planets, widening access to this important area for the European astronomical community. To reach this goal, development of astrometry at the level of 10 μas is essential. This unique capability will solve other fundamental problems such as globular cluster dynamics, calibration of the stellar mass-luminosity relation and evolutionary tracks of pre-main-sequence stars.

First statistically meaningful survey of the milliarcsecond structure in a sample of faint active galactic nuclei. In addition, the six baselines between the 8 m telescopes make the VLTI unique for obtaining the first images of inner structure of AGNs. These images will be directly comparable to ALMA images since they will have the same angular resolution. "Faint science" requires the development of off-axis fringe tracking (phase referencing). Phase closure imaging with the four UTs will accelerate the possibility to obtain images of bright extragalactic sources with high dynamic range.

The clarification of the jet formation mechanism both in galactic and extragalactic sources calls for even higher resolution and access to important emission lines, which is only possible by an extension of the wavelength coverage into the visible range. For very deeply embedded sources in star-forming regions the 20 μm range is essential.

In the long term, increasing the interferometric field-of-view is an important objective. The main motivations are astrometry and spectroscopy in crowded fields such as globular clusters and dense star-forming regions in the Milky Way and in the Magellanic Clouds. A very prominent goal is tracking orbits of individual stars within a few hundred to a few thousand Schwarschild radii of the black hole at the center of our Galaxy. For these stars, the orbital time scales are only a few years, and they are already in the relativistic regime. Gravitational lensing of the black hole, accretion events, and disk formation can also be studied. These observations require the development of advanced interferometric techniques such as homothetic mapping and off-axis astrometry.

5. Recommendations for the Further Development of the VLTI

Based on the scientific priorities, we recommend that an aggressive plan for PRIMA should be adopted, with the goal of implementing $10\,\mu$as astrometry in 2004, in order to search for exoplanets. In parallel, ESO should make sure that the first images of extragalactic objects can be obtained and that the necessary actions be taken to get to faint objects in 2006. This leads to the following specific recommendations:

5.1. Implementation of PRIMA

Phase 1 (2002-2004):

Hardware: 2 star separator systems for the ATs, 2 fringe sensor units, laser metrology with 5 nm accuracy.

Science goal: This will give the first phase of PRIMA a clearly defined scientific objective, namely $10\,\mu$as astrometry for extrasolar planet studies at about the same time as Keck, and well ahead of the launch of SIM.

The hardware configuration of phase 1 will allow phase-referenced imaging with the ATs. Some selected AGN can thus be studied with key goals such as the detection of the long sought after circum-nuclear gas/dust torus, measuring the size of broad line regions and jet physics. The observations of the Galactic Center region can also begin in this phase.

Phase 2 (2005-2008):

Hardware: Implementation of star separators on the UTs to enable faint science. One should start with equipping two UTs with star separators by 2006, so that first observations down to a limiting magnitude of $K \sim 20$ mag and $N \sim 11$ mag are possible. The project should then proceed at full speed to add star separators to the remaining UTs in order to allow imaging using all six UT baselines.

Science goals: The main thrust of this phase are the extragalactic observations described above. The large collecting area of the UTs will give access to fainter, more distant targets, and it will enable the use of fainter reference stars for off-axis fringe tracking. It is the combination of these two factors that will dramatically increase the scope of extragalactic programs.

This phasing of PRIMA is driven by the scientific objectives and competitive situation, but it also provides for the most logical sequence of technical developments. Letting the astrometry drive the first phase of PRIMA will ensure that stringent requirements on OPD measurement and control are met. Our experience with existing interferometers demonstrates that all aspects of the performance of the facility will benefit from a rigorous implementation of an astrometric mode.

It should be stressed that the scientific goals of PRIMA require fringe-sensing units that are as sensitive as possible. The precision of astrometric measurements will in many cases be limited by the photon-noise in the secondary channel, whereas the sky coverage in the faint-source mode depends very strongly on the limiting magnitude of the primary channel. No compromises should therefore be made in the performance requirements of the FSUs, and simultaneous operation in the H and K bands (which increases the SNR by a factor $\sqrt{2}$) is highly desirable.

We encourage ESO to involve the European interferometric community in the development of PRIMA to the largest extent possible. ESO should assemble a Science Team for PRIMA that combines the scientific and expertise available in the community, to guide the project. We strongly endorse ESO's plans to add a Project Scientist to the PRIMA team. An important task for the Project Scientist will be a detailed analysis of the key scientific programs defined above. We note that the success of the astrometric program depends on a careful preparation that includes the definition of the target and reference star samples. ESO's facilities including the first-generation VLTI instruments will have to play an important role during this preparatory phase.

ESO should consider enlisting external expertise for the detailed definition and implementation of PRIMA. Possible in-kind contributions from European institutions might help accelerate the successful completion of the program.

ESO's global projections for the total financial resources and manpower required for the implementation of PRIMA appear realistic; we strongly believe that the expected scientific return is well worth this investment.

5.2. Additional ATs, Closure Phase Imaging, and Future Instruments

We strongly recommend that ESO should actively pursue efforts to secure funding for a fourth AT. This will enhance the efficiency of VLTI operations by a factor 2 to 3. With four ATs, it will be possible to do astrometry and MIDI observations in parallel by devoting two telescopes to each program. The implementation of a four-telescope closure phase instrument would increase the number of simultaneously measured closure phases from one to three. This is a very cost effective way of improving the productivity of the VLTI. It should be noted that the most important objectives of the astrometric program, notably exoplanet surveys, will require repeated observations of large samples of stars. The scope and scientific impact of these projects are therefore strongly dependent on the observing efficiency and thus on the number of available ATs.

We urge ESO and the European interferometer community to jointly initiate the planning of second-generation instruments for the VLTI. A near-IR closure-phase instrument capable of combining at least six telescopes simultaneously should be a high priority. This would enable closure-phase imaging with the four UTs of objects fainter than the AT limiting magnitude, including an important set of active galactic nuclei. Stellar astrophysics would benefit tremendously from the gain in uv coverage afforded by this instrument. Other possibilities that should be considered include multi-way beam combination at $10\,\mu$m, instruments based on advanced detectors such as Superconducting Tunneling Junctions (STJs) or integrated optics.

We strongly support the ESO-ESA plan for a nulling instrument (GENIE) and recommend that the community will be involved in all aspects of this project. GENIE will develop both the technical expertise and astronomical basis for DARWIN. It should be pointed out that nulling is not possible without the implementation of stringent OPD control; GENIE will therefore benefit directly from the techniques developed for PRIMA.

We note that the VLTI programs involving use of the UTs depend critically on the availability and performance of their adaptive optics systems. It is therefore mandatory that ESO pays full attention to the timely delivery of the MACAO systems.

5.3. General recommendations

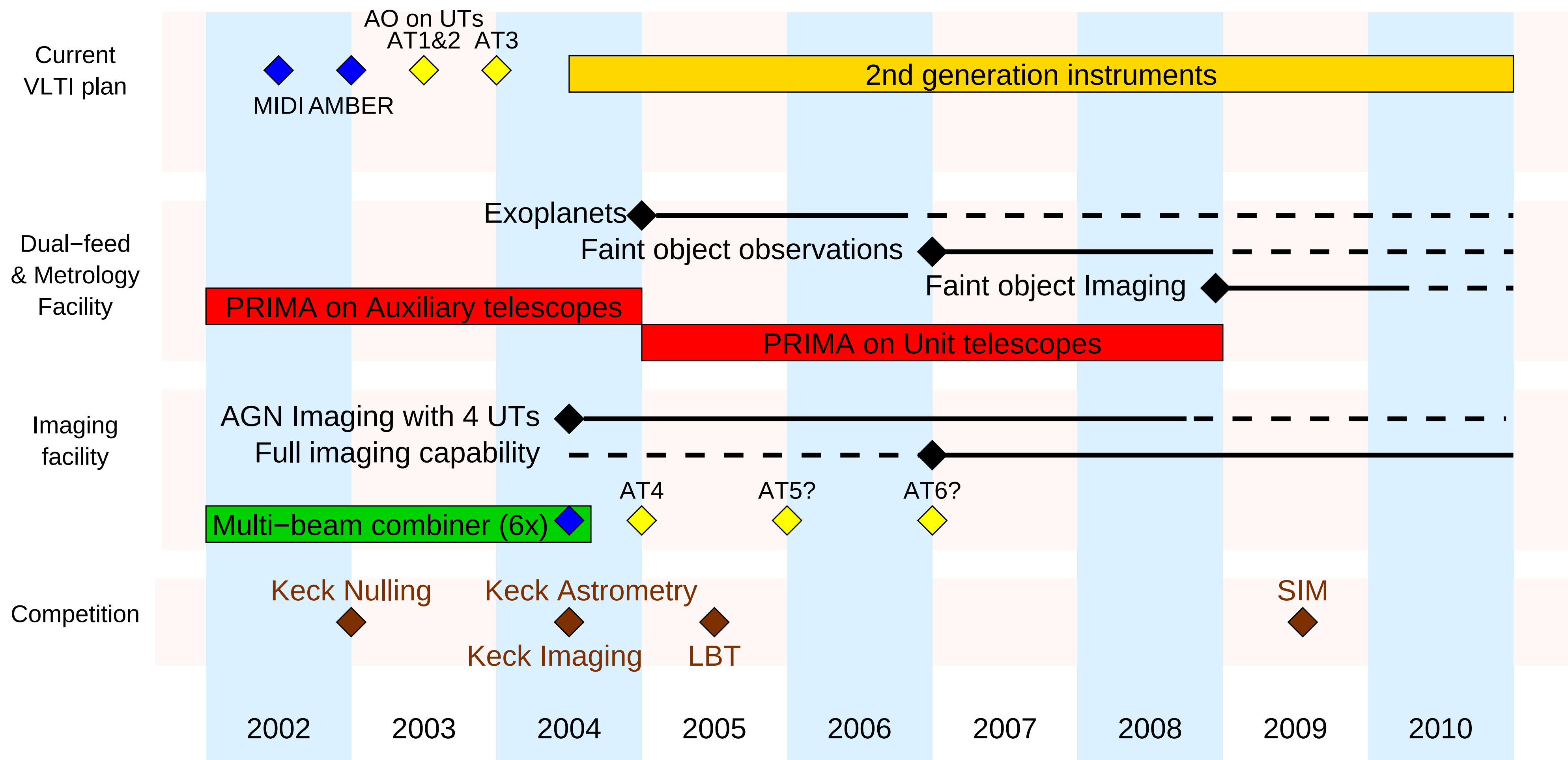
The success of ESO's interferometry program depends critically on the software for data management, data analysis, and scheduling. This leads to the recommendation that the VLTI team, together with the Data Management Division, has to develop an integrated plan immediately.

We foresee additional challenges for the operation of the VLTI by the large number of active high-speed servo systems (multiple telescopes, adaptive optics, fringe trackers, delay lines, choppers, etc.) that have to be run concurrently, and which interact with each other. We believe that systems engineering is already one the VLTI's major strengths compared to the main competitors, but we recommend a careful ongoing analysis of the operational requirements of an evolving, more complex VLTI.

We emphasize that it is important for the VLTI to produce and publish a number of first-rate scientific results as early as possible. This will keep the strong momentum generated by the successful acquisition of "first fringes", and will attract a large part of the astronomical community. In parallel, the results from the VLTI should be communicated to the press and general public in an accessible way.

ESO should continue to support small R&D programs in European institutions that will broaden the technology base of future interferometric instruments. Examples are the development of integrated optics for multi-way beam combination and of waveguides for the thermal IR, and the evaluation of optimized fringe tracking techniques.

Strengthening the relations with interferometry expertise centers in ESO member states will bring large benefits in areas such as tools for observing planning and data reduction, calibrator lists, education and training, and public relations.



Current
VLTI plan
Dual−feed
& Metrology
Facility
Imaging
facility
Competition
AO on UTs
AT1&2
AT3
MIDI
AMBER
2nd generation instruments
Exoplanets
Faint object observations
Faint object Imaging
PRIMA on Auxiliary telescopes
PRIMA on Unit telescopes
AGN Imaging with 4 UTs
Full imaging capability
AT4
AT5?
AT6?
Multi−beam combiner (6x)
Keck Nulling
Keck Astrometry
Keck Imaging
LBT
SIM
2002
2003
2004
2005
2006
2007
2008
2009
2010